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DOES DISTRIBUTION MATTER?

When Flexibility and Pareto-Efficiency in Greenhouse Gas Abatement

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Abstract:

This paper analyses banking and borrowing of carbon emission rights within the framework of a simple, integrated assessment model. Breaking the world economy in just two regions it will be shown: (1) Increasing when-flexibility in greenhouse gas abatement through banking and borrowing of carbon emission permits has a positive effect on welfare for regions with a poor endowment in carbon emission rights, but negatively affects rich-endowed regions. (2) Intergenerational fairness advocates intertemporal flexibility in greenhouse gas abatement, irrespectively of the initial allocation of carbon right. (3) Changing the degree of when-flexibility has only a small impact on global climate damages. (4) This is in contrast to the observation that the initial allocation of carbon emission rights has a significant impact on atmospheric carbon.

Keywords: Carbon rights, climate policy, integrated assessment, banking and trade.

JEL-Classification: Q4, F2

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1 Introduction

Global climate change defines a public good problem. Rich and poor, all live in the same greenhouse. It is easy to agree on strategies under which everybody will gain. But since it is expected that we need to proceed beyond *no regret* policies, there must be some arrangement for abatement and for burden-sharing. Economic efficiency ensures maximal potential for each participant to gain from such an agreement. This explains, why economists view efficiency as one of the major issues in global climate policy.

International trade of emission rights comes close to the economists' vision of an efficient internalization of the external effects of global climate change. To see this, suppose for a moment that transaction costs are negligible and that information is symmetrically distributed among parties. Then, according to the Theorem of Coase, without major changes in the historical ownership of labor, capital and other conventional resources, Pareto-efficiency in greenhouse gas abatement can be achieved through international negotiations.

However, the Coase Theorem not only formulates conditions that assure Pareto-efficiency through voluntary cooperation. It also states conditions under which it is feasible to separate the issue of efficiency from that of equity. Again, suppose for a moment that the benefits of avoiding climate change are completely captured by the market value of damages avoided - or, to express it more technically, suppose that global climate change affects production, but not utilities. Then the direct wealth effects of climate change are negligible and Pareto-efficient abatement policies are independent of the emission shares allocated to each region (for a discussion, see Manne and Olsen, 1996 or Manne, 1999).

This could have far reaching policy implications. A sharp distinction might be drawn between determining the global level of abatement and negotiating the cost sharing rules. For example, a credible, internationally accepted agency could set and implement optimal global emission targets. Thereafter, carbon emission rights are assigned exogenously to each region through international negotiations and economic efficiency is achieved through trading theses rights internationally. This won't be an easy task and depends upon the skill of the international negotiators. But it will be less complicated than negotiating simultaneously about the distribution of shares and emission reduction targets.

Reality, however, can be distracting. Despite being theoretically convincing there is serious objection against trading carbon rights on open international markets. The developing countries as well as most of the European nations argue that since the industrialized world is responsible for the majority of greenhouse gases it should take moral responsibility by reducing their carbon dioxide emissions first. The Kyoto Protocol reflects both views. In principle it allows for trading carbon emission rights. And it requires that the ANNEX I countries have to curb their carbon dioxide emissions, while developing countries are – at least in the near term - free from any duties to abate their greenhouse gas emissions.

The Kyoto protocol is not the focus of this contribution, but a question related to the Kyoto Protocol is raised in this paper: If international trade of emission rights is not a realistic policy option, do alternatives exist that also can stipulate efficiency in greenhouse gas abatement? Economists' conventional wisdom tells that the more flexible a policy intervention can be handled by those who should be regulated the lower are the welfare losses due to the specific policy measure. For an international agreement on greenhouse gas abatement this seemingly implies: A climate convention that keeps flexibility as high as possible is expected to be more cost effective than any other proposal.

Trade in carbon dioxide emission permits on open international markets increases the *where to abate* flexibility. *When to abate* flexibility in greenhouse gas emissions can be established through banking and borrowing of carbon rights. With banking and borrowing it is allowed either to save excess emission rights for future use, or to extend present emissions against future abatement. This should promote efficiency and reduce the costs of greenhouse policy simply by transferring abatement activities over time.

Banking of emission permits is by no means a new institution. The 1990 US Clean Air Act Amendments explicitly allow for trading and banking of sulfur dioxide (SO_2) emission permits. But there is a major difference between SO_2 and carbon dioxide (CO_2). Global climate change is a stock damage problem. It is driven by the accumulation of CO_2 in the atmosphere and is not directly associated with the flow of emissions. Therefore, the timing of emissions and damages is not coincident as in the case of SO_2. For this reason environmentalists conclude that excessive banking or borrowing of permits today could cause quite drastic damages in the future.

This immediately implies the question: Can banking and borrowing of carbon emission rights improve welfare, or does it threaten our common future? Unfortunately, the economic literature is not very helpful in answering this question. First, theoretical analyses are rather ambiguous about the welfare effects. For example, Biglaiser et al. (1995) show that intertemporal permit trade must not be efficient. Kling and Rubin (1997) conclude that although banking and borrowing emissions must not lead to a social optimum, banning intertemporal flexibility is not optimal.

Second, global trade in carbon emission rights is a feature of many integrated assessment models (for example, see Nordhaus and Yang, 1996, Manne and Richels, 1995, or Bernstein et al., 1999), but banking and borrowing of carbon permits is typically not included in these models. Only Manne and Richels (1995), Kosobud et al. (1994) and Westskog (2000) explicitly deal with banking and borrowing of carbon emission rights. However, these studies focus on cost efficiency, while taking certain emission reduction scenarios as given. As such they do not consider Pareto-efficient greenhouse gas abatement strategies. And they do not analyze the trade-offs between equity, efficiency and intertemporal flexibility.

Addressing these issues is the focus of this paper. We are not interested in considering gaming or threat situations. Instead within the framework of an integrated assessment model this paper analyzes the impact of *when to abate* flexibility on Pareto-efficient greenhouse gas abatement policies. In particular the questions will be considered: Can banking and borrowing of carbon permits enforce efficiency? Does banking and borrowing affect the atmospheric carbon concentration? Can the issue of efficiency in greenhouse gas abatement be separated from the problem of the international allocation of emission shares?

The rest of this paper is organized as follows: Section 2 carries out some simple analytical considerations. Section 3 characterizes the theoretical setting which is based upon a regional differentiated version of the MEDEA framework (see Stephan and Müller-Fürstenberger, 1998). Section 4 discusses the assumptions upon which the different scenarios of our numerical thought experiments are based and presents the major findings of our numerical analysis. Section 5 covers some concluding remarks.

2. Preliminary considerations

To clarify basic issues, let us carry out a simple analytical exercise. Suppose, R regions cooperate in the solution of the global greenhouse gas problem. Each region maximizes regional welfare over a time horizon of two periods. Global climate change is driven by the accumulation of greenhouse gas emissions. Economic damages are region-specific and directly enter into the economy-wide production functions.

In each period t = 1,2 regional consumption $c_r(t)$, r = 1,...R, is viewed as a function of greenhouse gas emissions $e_r(t)$:

$$(2.1) \qquad c_r(t) = \Phi_r(\Sigma_j e_j(t\text{-}1))F_r(e_r(t)).$$

The regional production functions F_r have the conventional properties, i.e., $F'_r(e_r(t)) > 0$, $F''_r(e_r(t)) < 0$. Φ_r is the region-specific environmental loss factor. It measures the fraction of conventional gross output that is at a region's disposal: The higher global emissions in the prior period, the lower is the value of Φ_r, hence, the lower will be the fraction of conventional wealth that is available for consumption in region r.

Now suppose, there exist perfect *when and where* flexibility in greenhouse gas abatement. If economic losses are negligible in the first period, then first order conditions for Pareto-efficiency can be observed through solving the Negishi-problem

$$(2.2) \qquad \max\{\Sigma_r\omega_r W_r[F_r(e_r(1)),\Phi_r(\Sigma_j e_j(1))F_r(e_r(2))] + \lambda(E - \Sigma_r e_r(1) - \Sigma_r e_r(2))\}.$$

E is the optimal stock of atmospheric carbon. W_r denotes the regional welfare function, and ω_r is the so-called Negishi weight attached to region r. Note that in equilibrium these weights are proportional to the present value of the respective region's wealth (see Manne and Olsen, 1996).

From (2.2) immediately follows a Solow-Stiglitz-type condition:

$$(2.3) \qquad \partial W_r/\partial c_r(1)F'_r(e_r(1)) + (\Sigma_j\omega_j\, \Phi'_j[F_j(e_j(2))])/\omega_r = \partial W_r/\partial c_r(2)F'_r(e_r(2)).$$

Pareto-efficiency is assured if each region is indifferent between extending carbon emissions marginally either in period 1 or in period 2. I.e., welfare gains, $\partial W_r/\partial c_r(2)F'_r(e_r(2))$, from increasing carbon emissions in period 2 by one unit have to be equal to the welfare effects of an additional unit of emissions in period 1. The later can be decomposed into direct and indirect effects on regional welfare. Direct effects, $\partial W_r/\partial c_r(1)F'_r(e_r(1))$, are positive, whereas the indirect ones, $(\Sigma_j\omega_j\Phi'_j[F_j(e_j(2))])/\omega_r$, are negative. The later are the weighted sum of those losses which region r imposes on each region j by extending carbon emissions in period 1. Therefore, overall losses depend upon the region-specific Negishi weights.

Now suppose that it still were feasible to allocate abatement activities freely in space, but no possibilities exist to operate *when to abate* flexibility. Then equation (2.2) has to be replaced by

(2.2a) $\max\{\sum_r \omega_r W_r[F_r(e_r(1)), \Phi_r(\sum_j e_j(1)) F_r(e_r(2))] + \lambda_1(E_1 - \sum_r e_r(1)) + \lambda_2(E_2 - \sum_r e_r(2))\}$,

where E_t, t = 1,2, are upper limits of global carbon emissions per period. Maximizing (2.2a) implies the first order conditions

(2.3a) $$\partial W_r/\partial c_r(1) F'_r(e_r(1)) + (\sum_j \omega_j \Phi'_j[F_j(e_j(2))])/\omega_r = \lambda_1/\omega_r,$$

(2.3b) $$\partial W_r/\partial c_r(2) F'_r(e_r(2)) = \lambda_2/\omega_r.$$

If abatement activities can not freely be allocated over time, as is supposed above, then optimality condition (2.3) will be satisfied by chance only. Therefore, if $\lambda_1 > \lambda_2$, region r would have an incentive to borrow carbon emission rights. Alternatively, region r is motivated to bank emission rights.

Finally, there are two important remarks. (1) Negishi-weights are part of the optimality conditions. Given their interpretation this suggest that there will be no separability between efficiency and equity in greenhouse gas abatement. (2) All regions react identically as (2.3a) and (2.3b) indicate. Obviously this is due to the fact that *where to abate* flexibility still prevails. Therefore, let us assume in the following that there were no international trade of carbon rights, but full *when to abate* flexibility. Then the first order conditions (2.3a) and (2.3b) have to be modified:

(2.4a) $$\partial W_r/\partial c_r(1) F'_r(e_r(1)) + (\sum_j \omega_j \Phi'_j[F_j(e_j(2))])/\omega_r = \lambda_r/\omega_r,$$

(2.4b) $$\partial W_r/\partial c_r(2) F'_r(e_r(2)) = \lambda_r/\omega_r.$$

Combining equations (2.4a) and (2.4b) yields (2.3), i.e., exactly the same first optimality condition as with full flexibility. When flexibility makes sure that the shadow price of carbon rights is equal across time. Note, however, that full flexibility imposes a stronger constraint on the allocation of carbon than when flexibility. With full flexibility, the shadow price of carbon permits is to be equal in both regions. Hence, for any pair of regions $r \neq j$

$$\omega_r\, \partial W_r/\partial c_r(1) F'_r(e_r(1)) = \omega_j\, \partial W_j/\partial c_j(1) F'_j(e_S(1))$$

and

$$\omega_r\, \partial W_r/\partial c_r(2) F'_r(e_r(2)) = \omega_j\, \partial W_j/\partial_{Sj}(2) F'_j(e_j(2))$$

applies, i.e., the marginal rates of substitution must be equated.

Of course, one could push the analytical reasoning further forward. However, the interactions between the banking and borrowing decisions of the single regions, Pareto-efficiency greenhouse gas abatement, burden sharing and equity are to complex to be traced through pure analytical analysis. Given these complexities numerical simulations might provide additional insight.

3. Regional MEDEA

In designing a numerically traceable model there is always a tradeoff between transparency, computational efforts and realism. As the purpose of our numerical thought experiments is insight not numbers, the theoretical framework is kept deliberately simple. To relate our results to the literature, numerical parameters from the RICE (see Norhaus and Yang, 1996), MERGE (see Manne and Richels, 1995) and MEDEA (see Stephan and Müller-Fürstenberger, 1998) integrated assessment models are taken over into our stylized-facts framework of the world economy.

There are two regions of the world. For vividness let them be called North (N) and South (S). North consists of the OECD countries including the former Soviet Union. Roughly this corresponds the so-called ANNEX I parties. South covers the rest of the world and should be viewed as an acronym for the developing part of the world.

We are not interested in the issue of intergenerational equity (see Stephan and Müller-Fürstenberger, 1998). Therefore, a descriptive rather than a prescriptive view is taken: Each region is represented as though it were an infinite-lived agent. Both, North and South, maximize the discounted value of consumption. South enjoys a higher rate of potential GDP growth than North. This immediately allows for the possibility of different rates of return on capital between the two regions (see Manne and Stephan, 1999).

Time is discrete and periods are one decade in length. Each region produces a homogeneous output that may be used for consumption, investment, net exports and to cover energy costs. Carbon-free energy resources such as hydro or solar are viewed as back-stop resources. They are provided at constant, but high marginal costs. Greenhouse resources such as oil, gas and coal are supplied at initially lower but increasing costs.

Among the various greenhouse gases, carbon dioxide (CO_2) is considered as the most relevant one. We neglect the cooling effects of aerosols and the heating effects of greenhouse gases other than carbon dioxide. We also neglect the thermal inertia lag between global concentrations and climate change. And we neglect climate externalities that are not valued in a market. Instead, global warming is directly attributed to cumulative CO_2 emissions and affects production of different regions of the world in different ways.

3.1 Climate-economy interaction

There are two channels through which the environment and the economy interact. One is the consumption of greenhouse resources which directly determines the flow of CO_2 emissions into the global atmosphere. The second link is provided though the concept of the *green output* by which global climate change is translated into its economic impact.

A two-box model is used to cumulate carbon emissions over time, and to translate them into global concentrations (for a detailed discussion, see Joos et al., 1999). At any point of time the stock of atmospheric carbon dioxide, Q(t), is a function of the former one, Q(t-1), and global past period emissions, s(t-1):

(3.1) $$Q(t) = \Psi Q(t-1) + \Theta s(t-1).$$

Ψ is the factor by which natural abatement reduces the current stock of atmospheric carbon. Θ is the fraction of past global emissions that has accumulated in the atmosphere.

The model is calibrated such that with zero abatement concentrations will rise from 353 ppm (the 1990 level) to 550 ppm (twice the pre-industrial level) by about 2070. This leads to damages of 3.5% of gross output in the South and 1.5% of GDP in the North. At other concentration levels, the regional damages are projected as though they were proportional to the square of the increase in concentrations over the 1990 level:

$$(3.2) \qquad \Phi_r(t) = 1 - [Q(t) / \Omega_r]^2.$$

Ω_r marks the critical value of the CO_2 concentration. At this atmospheric CO_2 perturbation, production in region r = N(orth), S(outh) is reduced to zero.

$\Phi_r(t)$ is the so-called environmental loss factor. It indicates economic damages induced by global climate change in region r = N,S. The corresponding economic costs are measured in terms of forgone GDP. I.e., if the atmospheric stock of carbon dioxide is raised to levels Q(t) above pre-industrial atmospheric carbon, then in region r the productivity of inputs is reduced such that only $\Phi_r(t)$ percent of the original gross production is at the region's disposal.

3.2 Production, emissions and abatement

Principally, there are two ways to reduce CO_2 emissions. One is to replace greenhouse fuels by carbon-free energy inputs. A second option is to uncouple economic growth from fossil fuel consumption by increasing the energy efficiency and by substituting capital for energy. To capture both possibilities, the regional production possibilities are represented through a nested constant elasticity of substitution (CES) production functions[1]:

$$(3.3) \qquad y_r(t) = [\beta_1(l_r(t)^{\alpha}\, k_r(t)^{1-\alpha})^{\varepsilon} + \beta_2(e_r(t))^{\varepsilon}]^{1/\varepsilon}.$$

Capital $k_r(t)$, labor $l_r(t)$ and energy inputs $e_r(t)$ together produce the conventional (i.e., without climate effects) output, $y_r(t)$. β_1 and β_2 are CES-coefficients derived from base year data, and ε is the CES elasticity of substitution between capital/labor and energy.

Substitution between capital and labor is described by a Cobb-Douglas formulation where α is the corresponding parameter. Total energy inputs into regional production,

$$(3.4) \qquad e_r(t) = f_r(t) + n_r(t),$$

are the sum of flows of fossil fuels $f_r(t)$ and of backstop energy resources $n_r(t)$.

3.3 Material balance of produced goods

Climate change negatively affects the productivity of the regional economies (see (3.2)). Only the fraction $\Phi_r(t)$ of conventional gross output $y_r(t)$ is still at their disposal. Within each region r,

[1] For better readability parameters do not carry regional indices.

green output $\Phi_r(t)y_r(t)$ can be consumed, invested into conventional capital formation, or used to supply either greenhouse resources or carbon-free energy.

Energy supply costs are measured in units of gross production. Marginal costs b_r of carbon-free energy are constant, but approximately four times as high as costs of greenhouse resources in the initial year. Marginal costs $a_r(t)$ of greenhouse resources increase over time, depending upon the cumulated extraction in prior periods.

Energy producing and consuming devices can be replaced only gradually. To prevent an excessively rapid market penetration once renewable resources become competitive, it is assumed that a global cutback of conventional energy systems cannot be faster than 20% per decade. That is:

$$(3.5) \qquad f_r(t+1) \geq 0.8 f_r(t).$$

With this formulation there is the possibility that market prices of energy temporarily overshoot the marginal costs of the renewable resources.

Regional output is considered as numeraire that can be traded internationally. Therefore, if $x_r(t)$ denotes net-exports, $c_r(t)$ consumption, and $i_r(t)$ investment in conventional capital, then for each period t

$$(3.6) \qquad \Phi_r(t)y_r(t) \geq c_r(t) + i_r(t) + x_r(t) + a_r(t)f_r(t) + b_r n_r(t)$$

is the material balance of commodities produced and traded in region r. Finally, since net-imports have to balance out in each period t, condition

$$(3.7) \qquad x_N(t) + x_S(t) = 0$$

has to be obeyed globally.

3.4 Intertemporal decisions

At any point of time t, the regional endowment $k_r(t)$ in physical capital depends upon investment activities, $i_r(t-1)$, and the former capital stock, $k_r(t-1)$

$$(3.8) \qquad k_r(t) = (1-\upsilon_r)k_r(t-1) + i_r(t-1),$$

where υ_r is the regional capital depreciation rate.

At first glance, the natural approach to the economics of global climate change would be to employ an overlapping generations model. It was shown, however, that under reasonable assumptions both an infinitely-lived agent framework and an overlapping generations model will identify the same greenhouse policies as being efficient (see Stephan et al., 1997). Therefore, without loss of generality it is supposed that for striking an optimal balance between consumption, physical investment and greenhouse gas abatement regions follow a Ramsey path.

Let δ be the social discount rate, then consumption, production, investment into physical capital and greenhouse gas abatement are determined in each region r = N,S, as if a policy maker has maximized the discounted sum of the logarithm of consumption, $c_r(t)$

(3.9) $$W_r = \Sigma_t \, \delta^{-t} \ln(c_r(t)).$$

If there is no capital mobility and no investment into greenhouse gas abatement, both regions would develop independently. But if the regions agree to cooperate on greenhouse abatement, prices, supplies and demands are generated through a multi-region multi-period general equilibrium model. Solutions are obtained via Rutherford's sequential joint maximization method - a specialization of the Negishi approach (see Rutherford, 1999).

4. Beyond Kyoto

4.1 Scenarios

Today, there is general agreement that without participation of the developing countries the human society will not be able to cope with the threat of a global climate catastrophe. This and the fact that the Kyoto proposal is of a limited time horizon only suggests (1) to apply a time horizon of more than a hundred years, (2) to suppose that all parts of the world contribute to the solution of the global climate problem.

SCENARIO	*PROPERTIES*
NOFLEX	No when, no where flexibility
BABO	Full when flexibility, no where flexibility
PCAP	Per capita distribution of carbon shares
GRAND	Status Quo distribution of carbon shares
PARETO	Efficient distribution of carbon shares

Table 4.1: Flexibility scenarios[2]

Given these presumptions five scenarios are considered which differ with respect to the degree of *when flexibility* as well as in the initial distribution of carbon rights (see Table 4.1). NOFLEX and BABO represent two polar cases of *when flexibility,* while PCAP and GRAND are polar with respect to the initial assignment of carbon rights (see Figure 4.1). GRAND is a so-called grand-fathering allocation as it pins down carbon shares according to the emissions of the benchmark year (1990). In PCAP shares smoothly move from grand-fathering to a

[2] Parameters for the computational experiments are benchmarked against 1990 data (for details, see Appendix I). And to reduce end-of-time-horizon effects, results are reported till 2100 but computations are carried out till 2200.

equal-man-equal-rights distribution. To be more precise, the North's share declines from a 45% share in 2000 to a 10% share in 2050. This scenario clearly favors South, whereas GRAND favors the North.

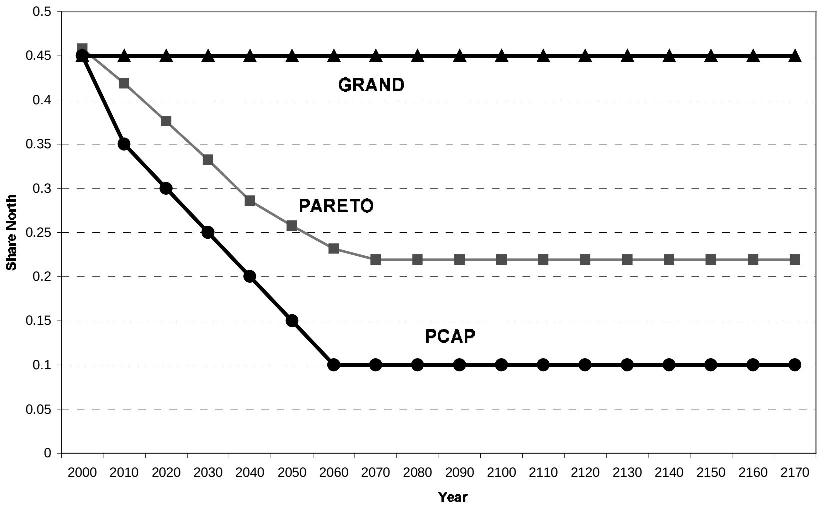

Figure 4.1: Carbon Shares (North)

Note finally, PARETO is a distinguished scenario. In PARETO carbon rights are allocated such that marginal abatement costs are equal across regions. Therefore, efficiency in greenhouse gas abatement is automatically assured.

Before presenting results, let us have a look at the different flexibility designs. As the acronym NOFLEX indicates, emission permits cannot be traded nor is it feasible to bank and borrow them. Therefore, if $m_r(t)$ is the share of carbon emission rights attributed exogenously to region r, this region is authorized only to consume its own endowment, $m_r(t)w(t)$, of carbon dioxide emissions in period t. Note, since optimal global CO_2 emission targets, w(t), are determined endogenously for each scenario, NOFLEX assures optimality in global greenhouse gas abatement, but - as we expect - in a costly way.

When flexibility is given if the regional economies are allowed to allocate freely their endowment of carbon emission rights over time. BABO refers to this situation:

(4.1) $$\sum_t[m_r(t)w(t) - s_r(t)] = 0.$$

As (4.1) indicates, with BABO regional economies may save and borrow carbon emission permits, but they are not allowed to sell or buy them.

At first glance it is expected that because of increased flexibility, banking and borrowing of carbon emission rights should reduce costs and positively affects welfare. However, there could be two countervailing effects. For a first illustration, consider the PCAP scenario. Costs of abatement are borne early and benefits do not accrue until the distant future. Therefore, at least the North has an incentive to borrow carbon emission rights. This might lead to what environmentalists fear - higher atmospheric carbon concentrations, hence higher ecological damages and - as a consequence - welfare losses.

Moreover, as the global climate is a public good, the South is affected by the North's borrowing decision. In other words, if the North operates the borrowing option independently, this might create intertemporal external effects on the southern economies. For an optimal solution these effects have to be internalized. I.e., the South has to compensate the delay in greenhouse gas abatement by the North through increasing his abatement activities in the near distant future. Again this can imply welfare losses, now for the southern economies.

4.2 Atmospheric carbon

Does *when* flexibility in greenhouse gas abatement lead to what environmentalists fear - excessive borrowing of carbon emission permits at early periods?

Figure 4.2: Atmospheric Carbon

The answer is neither no nor really yes (see Figure 4.2). Increasing *when* flexibility forces higher atmospheric carbon concentrations. Depending upon the scenario, peak-levels vary from 660 ppm to 710 ppm. This implies market damages between 3.9% and 4.9 % GDP in the North, while the South experiences GDP-losses in the order of 7.8% to 9.8%. These are not dramatic differences, but nevertheless significant.

Our simulations reveal that *where* flexibility as well as *where-and-when to abate* flexibility yield exactly the same development of atmospheric carbon as PARETO, irrespectively to the initial allocation of carbon rights. This supports the well-known hypothesis that the optimal carbon stock is independent of the initial allocation emission shares if it were feasible to trade carbon rights on open international markets. However, if *where to abate* flexibility is absent and *when* flexibility prevails only, the Coasian argument does not apply.

It might be viewed as a surprise that *where to abate* flexibility is associated with the highest carbon levels. However, there two explanations. First, our model does not include non-market damages. Negative external effects of global climate change can be fully internalized by assigning carbon emissions rights, and Pareto-efficiency is assured through trade. Second, trade-induced economic growth outweighs higher climate damages. That is, an efficiently organized economy may provide higher green GDP by producing more conventional output as well as higher emissions.

4.3 Regional emissions

When flexibility does not significantly affect the atmospheric accumulation of carbon, but the development of regional emissions changes notably as Figures 4.3a,b and 4.4a,b illustrate.

Figure 4.3a: Carbon Emissions North GRAND

Figure 4.3b: Carbon Emissions South GRAND

It is immediate from Figures 4.3a and 4.3b that a region's decision either to bank or to borrow carbon permits depends upon its initial carbon share. In GRAND, North uses the banking option to postpone emissions relative to NOFLEX almost till the end of the century. The South, in turn, heavily borrows carbon permits, in particular during the decades after 2030. This indicates that under GRAND burning fossil fuels has a relatively high marginal value to the South, whereas the North reacts by cutting back emissions.

Figure 4.4a: Carbon Emissions North PCAP

Figure 4.4b: Carbon Emissions South PCAP

If carbon rights are allocated according to PCAP, borrowing appears favorable to North while South banks (see Figures 4.4a and 4.4b). The argument behind this observation is the same as in GRAND with reversed roles.

Both in the PCAP and the GRAND distribution of carbon rights *when* flexibility stipulates emissions to approach the PARETO path. Indeed, till the middle of our century PARETO and BABO coincide. Moreover, as can be observed for the numerical parameters employed, one region's borrowing is exactly offset by the other region's banking. This explains the almost negligible differences in atmospheric carbon.

Summing up, our simulations suggest: (1) Differences between NOFLEX and BABO are small in terms of atmospheric carbon concentration, while differences in the initial allocation of carbon rights significantly influence carbon peak levels. (2) If banking and borrowing of carbon rights is allowed, this affects regional emissions. In particular, one region's borrowings are completely offset by the other region's banking. (3) If carbon emission rights are in addition traded on an open international market, then allowing for banking or borrowing does not impose additional costs in terms of climate change.

4.4 Aggregated welfare

Now let us single out how the different flexibility regimes affect present values of regional welfare. If expressed in per cent deviations from PARETO values, welfare effects are extremely small (see Figures 4.5a and 4.5b). Typically, they stay below the half-percent margin.

Figure 4.5a: Overall utility North

Figure 4.5b: Overall utility South

That the initial allocation of carbon rights influences the present value of regional welfare is unambiguous. Independent of the degree of flexibility in greenhouse gas abatement, North is best with GRAND (see Figure 4.5a). Relative to PARETO the North gains both in the BABO and the NOFLEX scenario. In PCAP, North looses welfare relative to PARETO both with and without *when* flexibility. As such, North's best choice would be GRAND - independent of the degree of intertemporal flexibility.

For the South, the situation is just reversed (see Figure 4.5b). If the South had a choice, in any case he would vote for PCAP. With GRAND, compared to PARETO the South suffers welfare losses both in the BABO and NOFLEX scenario.

Our results show that contrary to the win-win situation that can be observed if there is free trade in carbon rights, banking and borrowing is a win-loose option. Regions with a high initial endowment of carbon rights are suffering from *when* flexibility, whereas regions which are poorly equipped only can gain from intertemporal flexibility in greenhouse gas abatement. Adding *where* flexibility even enhances this situation (not shown in the Figures). This is not to big a surprise. Economists' conventional wisdom tells that welfare can decrease with *when to abate* flexibility. First, an international agency which seeks to promote Pareto-efficiency by issuing permits based on flows of emissions looses control over the dating of emissions, if banking and borrowing is allowed. Second, Leiby and Rubin (2001) have shown that banking can lead to welfare losses unless carbon emission rights are traded at the correct intertemporal exchange rate. The latter is determined by the ratio of current marginal stock damages to discounted future value of marginal stock damages less the decay rate of emissions.

4.5 Per-capita consumption

Present values bear no information about the intertemporal distribution of welfare. However, since regional welfare is directly related to the logarithm of consumption (see (3.9)), per-capita consumption might be used as rough indicator, how welfare is distributed over time.

Figure 4.6a: Consumption North GRAND

Figure 4.6b: Consumption South GRAND

Figure 4.7a: Consumption North PCAP

Figure 4.7b: Consumption South PCAP

Again PARETO is taken as reference. Compared to other scenarios, it exhibits the lowest intertemporal variations in per-capita consumption. As such PARETO is not only efficient, but can also be regarded as 'fair'.

As Figures 4.6a,b and 4.7a,b suggest both the initial allocation of carbon rights and the degree of abatement flexibility affect the intertemporal distribution of welfare. To see this, let us first consider the GRAND initial allocation of carbon rights. In the North there are winners and looser in term of per-capita consumption relative to PARETO. In the middle of this century there is a trough in per-capita consumption, making people worse in any flexibility scenario if compared to PARETO. Nevertheless, there are obvious differences among the different flexibility scenarios. Intertemporal distribution effects are more pronounced in NOFLEX than in BABO. As such BABO seems favorable from the perspective of intergenerational fairness, although NOFLEX is superior from an overall utility perspective.

In South, reducing flexibility has the same impact on consumption as in North, but even more pronounced (see Figure 4.6b). NOFLEX leaves generations for a whole century worse than PARETO, again with a trough in the middle of this century. *When* flexibility flattens this pattern - just as it did in North.

Now let us turn to the PCAP initial allocation of carbon rights. As can be seen from Figures 4.7a and 4.7b, the impact of different flexibility regimes is less pronounced than it was in the GRAND allocation. In the North, the distributional effect of *when* flexibility is smooth, with generations living in the middle of the 21st century gaining most. In the South per-capita consumption is almost insensitive against changing the degree of *when to abate* flexibility. Some generations are winning, some are losing from BABO. In the very long-run (beyond 2100), NOFLEX is clearly superior to BABO.

To sum up, *when* flexibility is a mean to foster intergenerational fairness across all regions. Keeping in mind, how small the effects are on present values of regional welfare, banking and borrowing seem to be a policy tool that allows to scope with the issue of intergenerational distribution effects.

5. Conclusions

Among economists there is almost general agreement that *where* flexibility should be an integral part of an international treaty on climate policy. The reasons are well-known. International trade of carbon emission rights ensures cost-efficiency irrespectively to the initial allocation of carbon rights and allows to separate the issues of efficiency from that of equity.

Where flexibility is not in the focus of this paper. Instead, banking and borrowing of carbon emission rights is considered as an alternative for creating flexibility in greenhouse gas abatement. However, does w*hen* flexibility work in a similar direction as trade in carbon rights does? In principle the answer is 'yes', but needs some qualifications.

In contrast to *where* flexibility w*hen to abate* flexibility does not guarantee that the optimal carbon accumulation is independent of the initial allocation of carbon rights. Different initial sharing rules clearly influence the development of atmospheric carbon concentration. Coasian separability does not apply, although *when* flexibility moves the development of atmospheric carbon towards the Pareto-efficient concentration - however, without full convergence.

W*here* flexibility represents a win-win situation. All regions can improve welfare through trading carbon emission rights. *When* flexibility creates a win-loose option. Regions that have a high initial endowment in carbon rights suffer from intertemporal flexibility, while regions with a small carbon budget can gain from it. Therefore, *when* flexibility is likely to counteract unequal initial distributions of carbon shares. This is consistent with our observation that *when* flexibility seems to support fairness between generations and across regions.

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Figures

Figure 4.2: Atmospheric Carbon

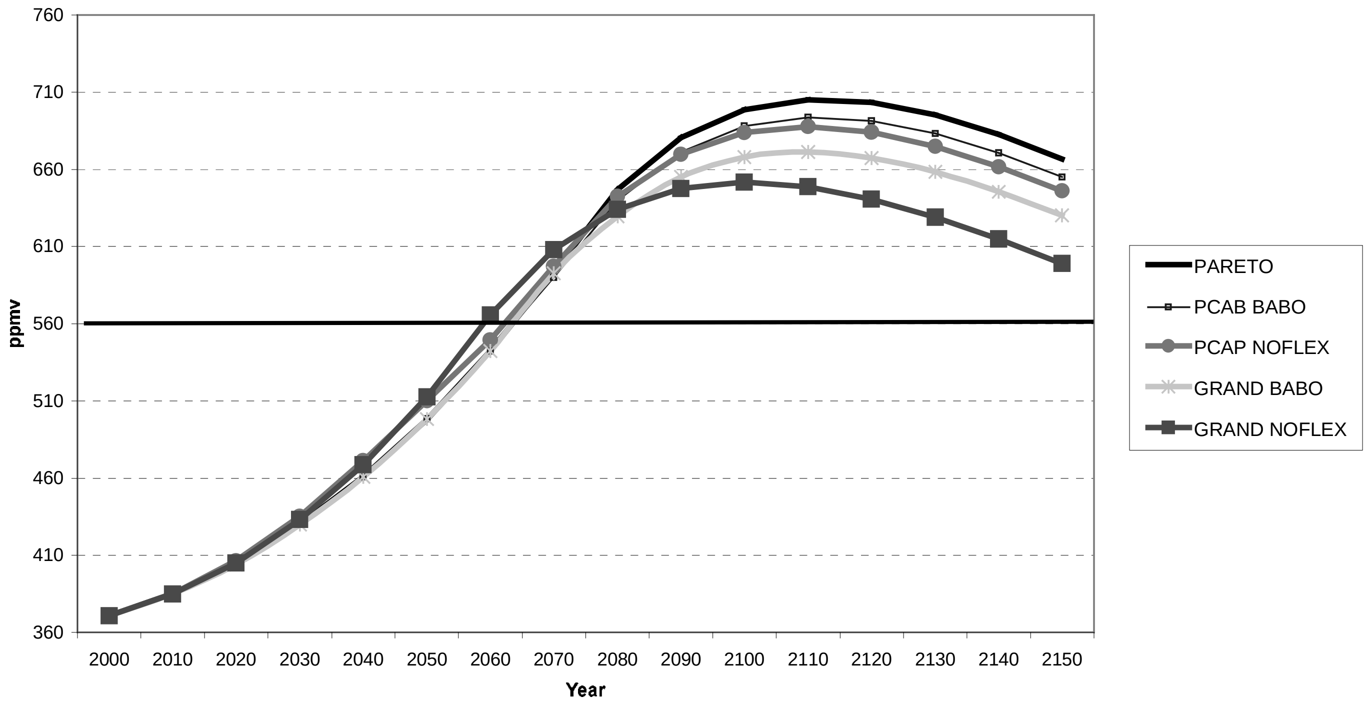

Figure 4.3a: Carbon Emissions North GRAND

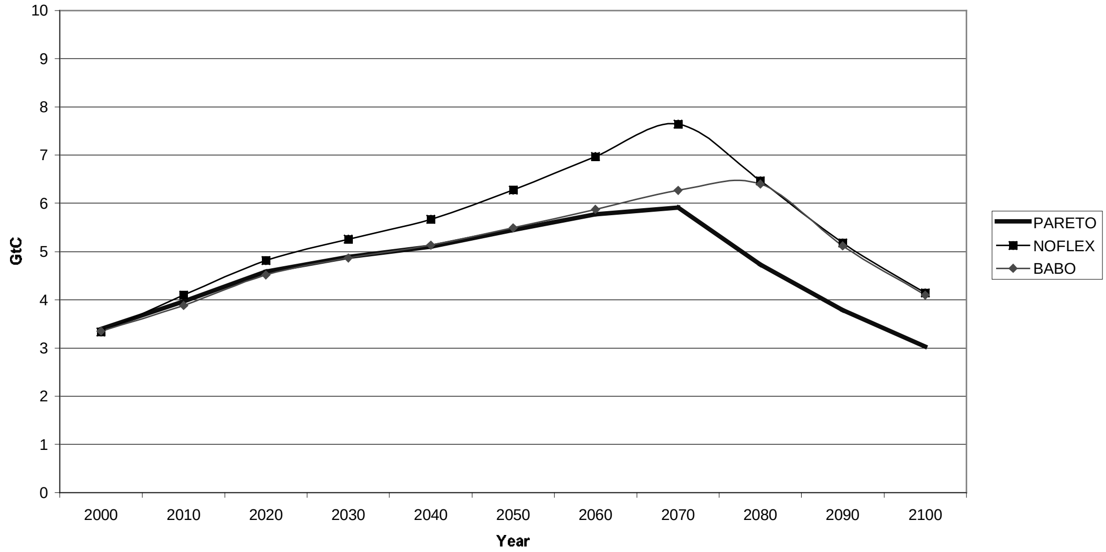

Figure 4.3b: Carbon Emissions South GRAND

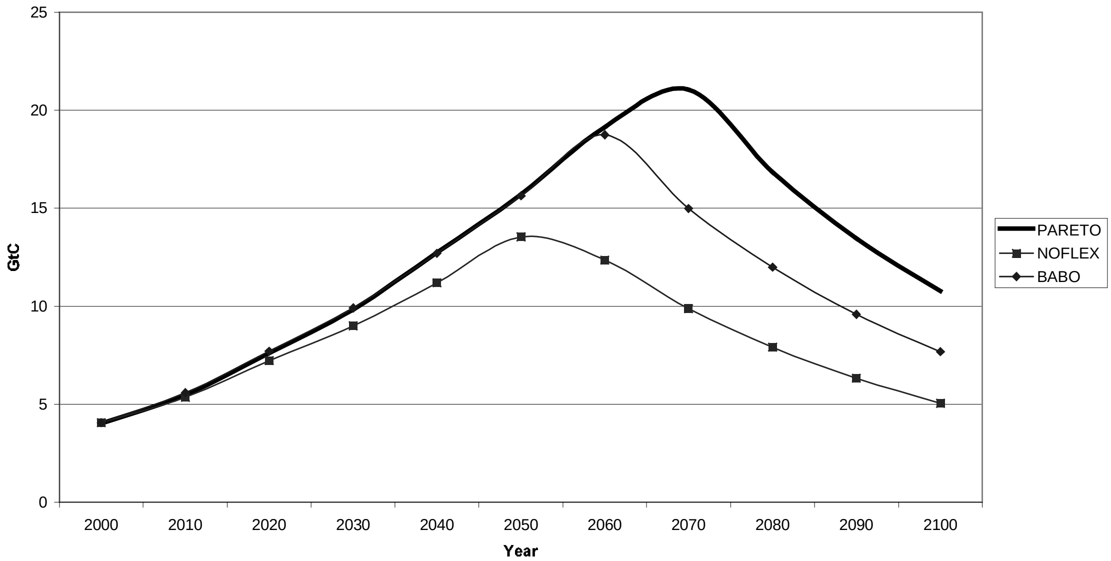

Figure 4.4a: Carbon Emissions North PCAP

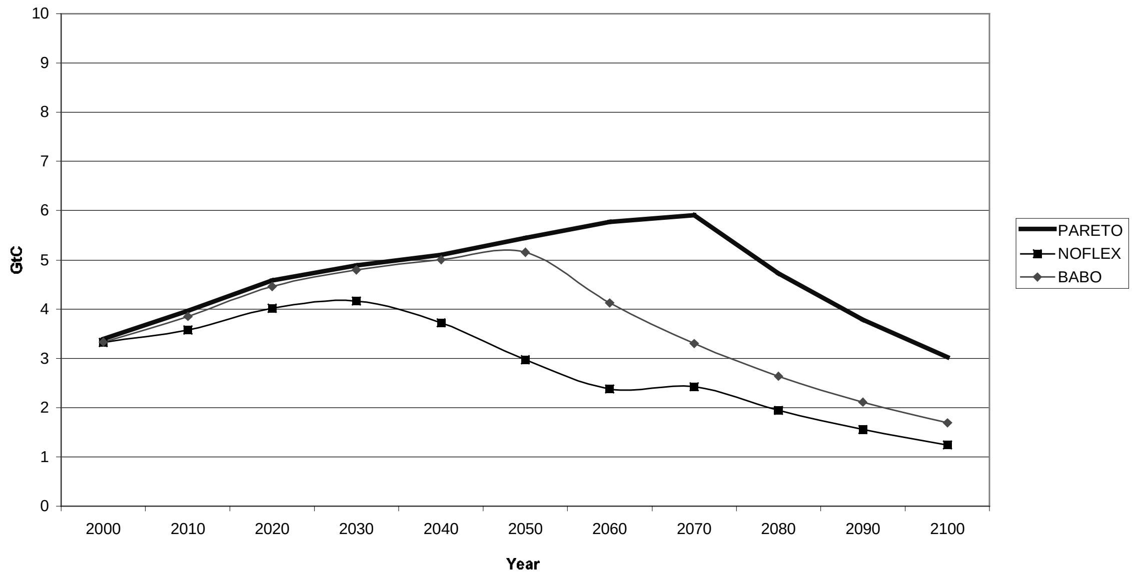

Figure 4.4b: Carbon Emissions South PCAP

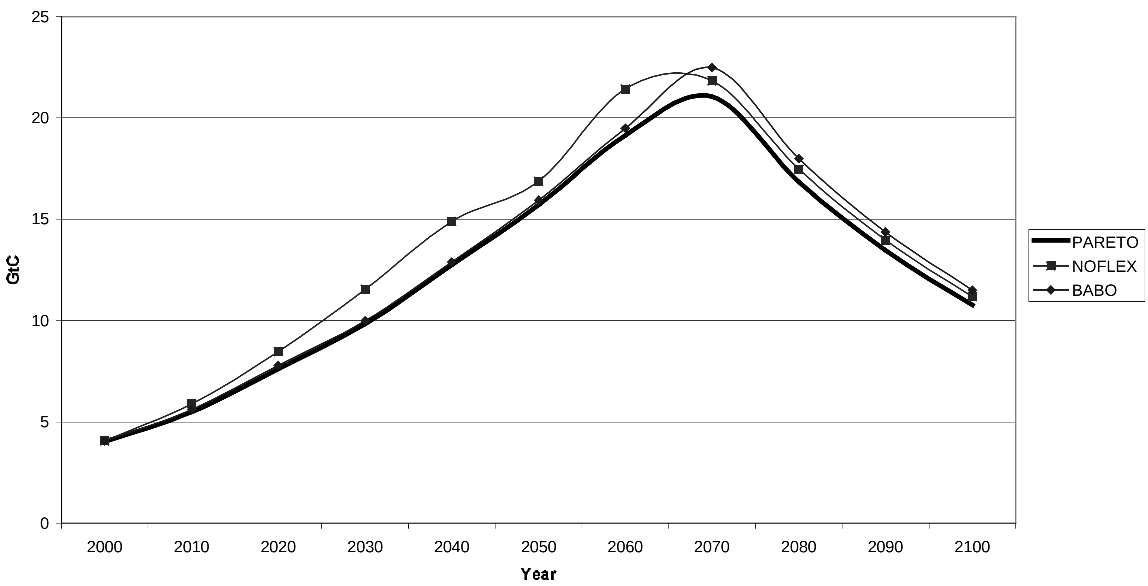

Figure 4.5a: Utility North

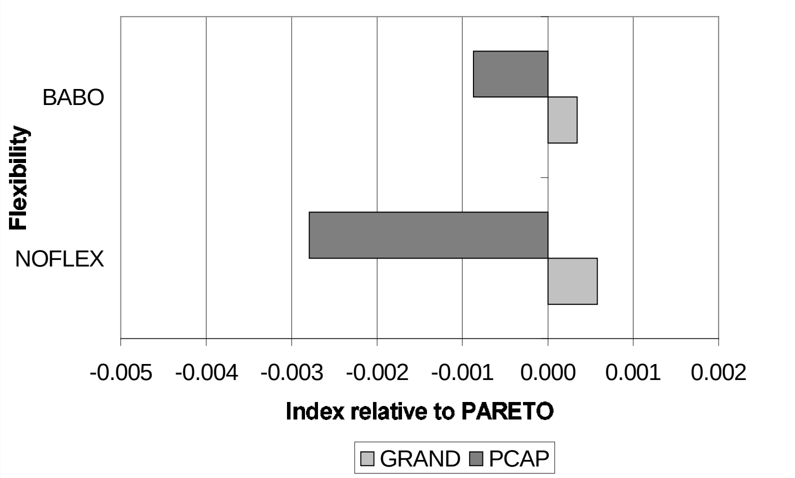

Figure 4.5b: Utility South

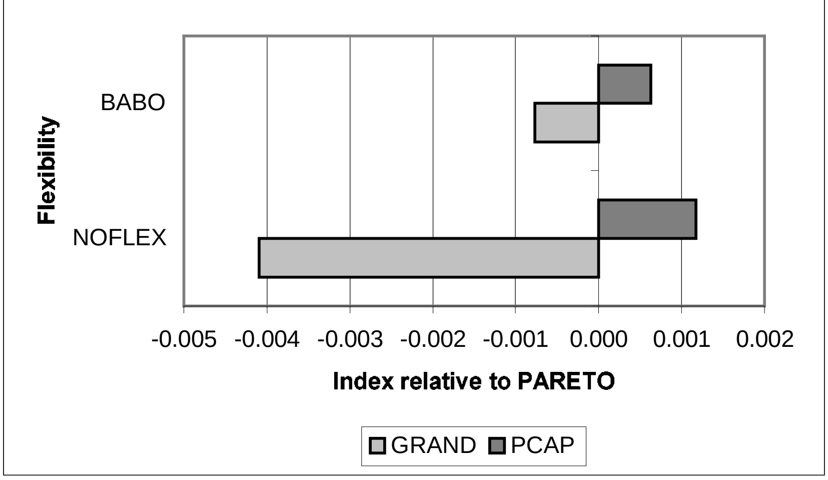

Figure 4.6a: Consum North GRAND

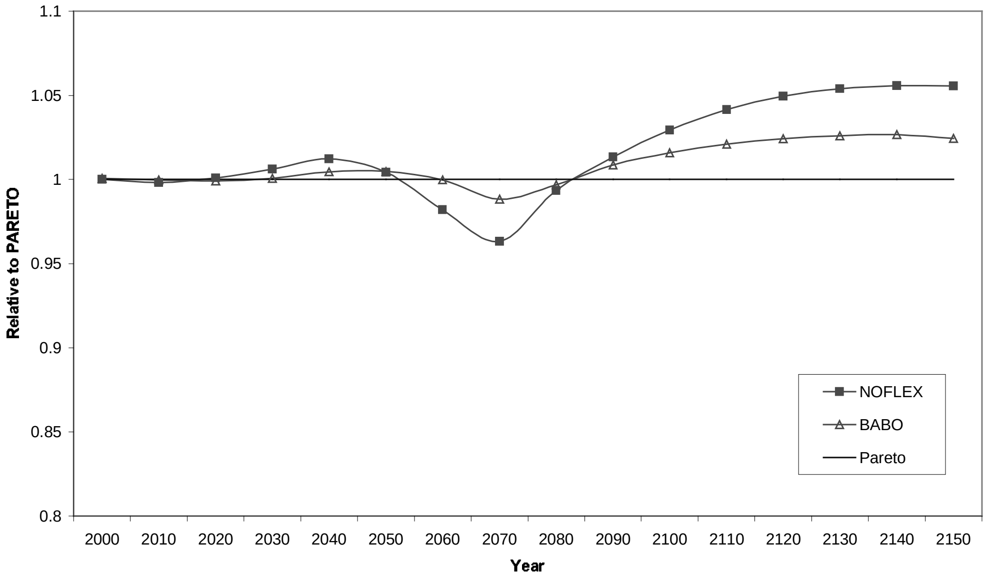

Figure 4.6b: Consum South GRAND

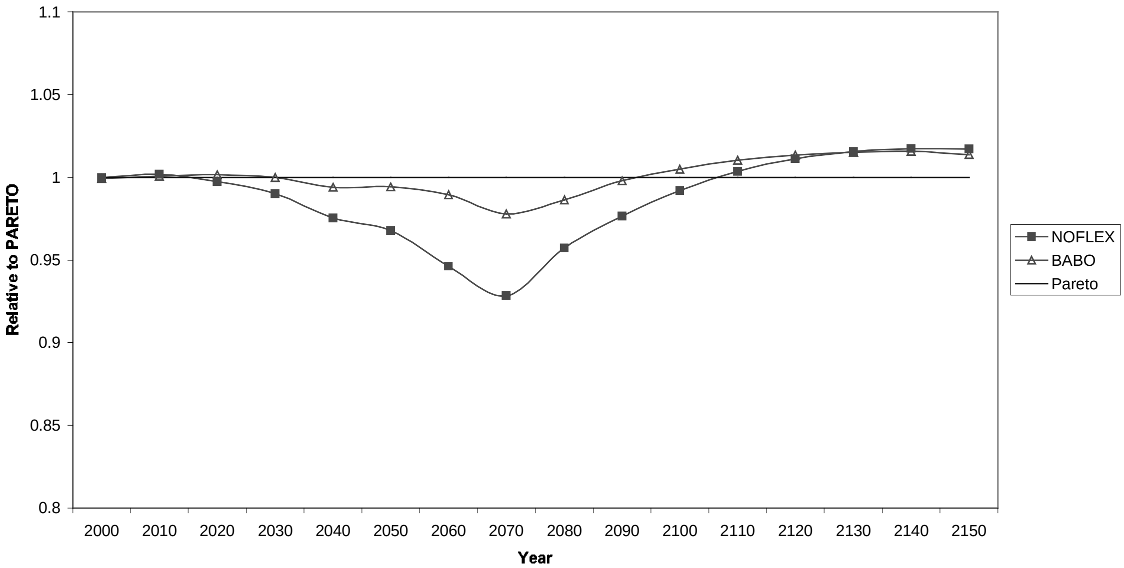

Figure 4.7a: Consum North PCAP

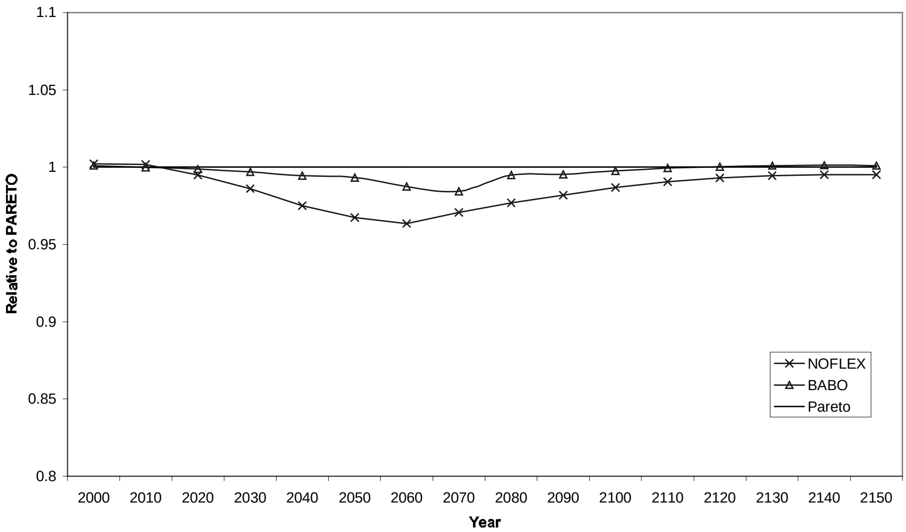

Figure 4.7b: Consum South PCAP